Development and meteorological applications of the NOAA/NCAR high-power 2µm Doppler lidar

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Abstract: The NOAA High-Resolution Doppler Lidar (HRDL) has recently undergone considerable improvements by a joint NOAA/NCAR team. Results achieved on ground-based and shipborne platforms demonstrate the instrument's high value for atmospheric boundary layer research.

OCIS codes: (280) Remote sensing, (280.3640) Lidar, (000.2170) Equipment and techniques

1. Introduction

A joint collaboration between the National Center for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration (NOAA) has succeeded in providing an advanced laser transmitter for the High-Resolution Doppler Lidar (HRDL). We discuss the improvements which led to a significantly better performance of the laser transmitter. Furthermore, a motion compensation system has been developed to allow good pointing stability on shipborne platforms. Atmospheric parameters which can be investigated include the convective boundary layer height, aerosol backscatter profiles, and line-of-sight (LOS) or radial velocity profiles with typical averaging times of 1s or less and a range resolution of 30m. An important feature of HRDL is its rapid scanning capability, which allows the investigation of these parameters in three dimensions. We present several measurement examples of the NAURU99 campaign (see http://www.etl.noaa.gov/nauru99/) and the CASES-99 campaign (see http://www.colorado-research.com/cases/CASES-99.html). The results demonstrate that is it particularly the investigation of parameters in two or three dimensions which provides important data for atmospheric boundary layer research improving considerably our knowledge on boundary layer processes.

2. Laser transmitter

Previously, HRDL was prone to optical damage in the laser transmitter so that during operation in the field the average power was limited to 0.1W (0.5mJ at 200Hz). Additionally, the frequency stabilization routine was very sensitive to vibrations which hindered routine application and reduced the duty cycle considerably in rough environments.

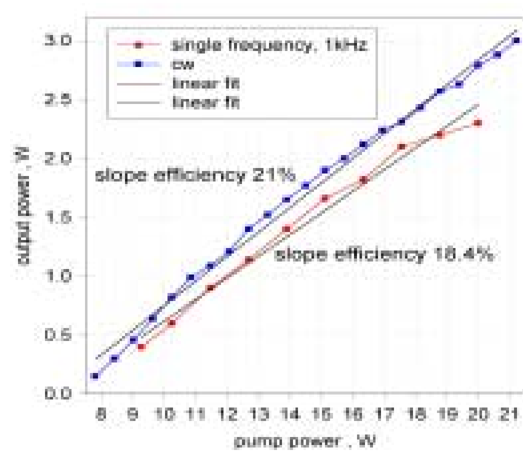

Fig. 1. Output power of the HRDL laser transmitter as a function of pump power for cw and pulsed operation.

We constructed a new laser cavity to overcome these problems. Emphasis focused on laser crystal cooling and the design of a dynamically stable resonator. With these improvements we were able to increase the pulse energy to more than 3mJ at 200Hz. At 1kHz we achieved an average power of 2.3W before the cavity became unstable. All these values correspond to TEM_{00} single frequency operation. Fig. 1 presents the output power of the HRDL laser transmitter. In cw operation we achieved a slope efficiency 21% which reduced to 18.4% while operating with a repetition rate of 1kHz. A new feedback loop for frequency stabilization has been developed [1]. Based on a phase modulation technique [2], which we modified for our purpose, an error signal exactly at resonance of the local oscillator in the slave cavity has been produced. Advantages of the new technique are a large capture range of the error signal of ±40MHz, a large bandwidth of the feedback loop (currently 2.5kHz), and a very low frequency chirp of the laser pulse.

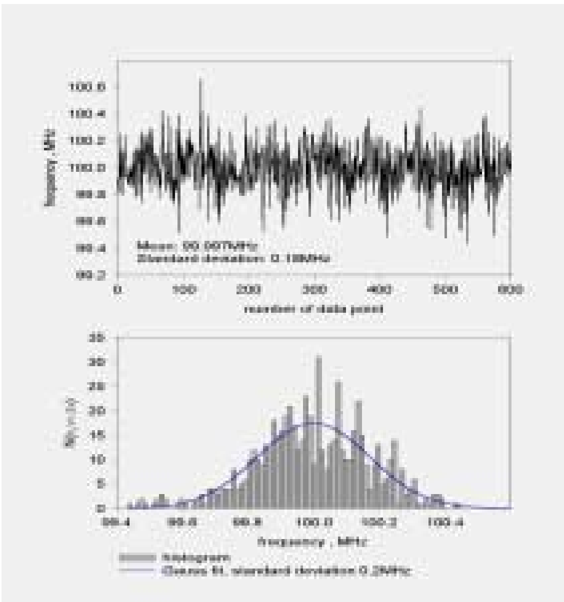

FIG. 2. Short-term frequency stability of the laser transmitter measured using the beatnote signal between the local oscillator and the pulsed laser.

Fig.2 shows the short-term frequency stability of the laser transmitter. The standard deviation is 0.2MHz rms which was maintained with 100% duty cycle even in heavy seas on the NOAA ship R/V Ronald H. Brown in the tropical western Pacific. The frequency fluctuations can be approximated by a normal distribution. After proper alignment of the laser system, a mean frequency offset of 99.997MHz between the local oscillator and the pulsed laser was achieved which corresponds to an error in the wind velocity of just 3mm/s even disregarding shot-to-shot frequency correction. In the future, the new feedback loop will allow for airborne applications of HRDL.

3. Measurements

The remodeled HRDL participated in several field campaigns where it proved to be an excellent tool for the investigation of boundary layer processes.

During the NAURU99 field campaign HRDL was operated on the NOAA ship R/V Ronald H. Brown. We investigated turbulent exchange processes, aerosol particles, and clouds in the marine boundary layer over the tropical western pacific. One interesting finding was the observation of a second turbulent layer above the mixed layer.

Another important issue during the NAURU99 campaign was the investigation of the Nauru island effect. Being the only instrument on the ship featuring clear-air 3-d scanning capability with high resolution and signal-to-noise ratio, HRDL was indispensable for the observation of turbulence, aerosols, clouds, as well as the diurnal cycle of Nauru's thermal internal boundary layer (TIBL). We made measurements of the diurnal cycle of Nauru's TIBL by continuous circumnavigations of the island for 24h. Using cross-shiptrack RHI scans we measured the evolution of the 3-d TIBL and its wake above and around Nauru. The height of the mixed layer was detected by the first minimum of the gradient in the backscatter signal [3,4]. For the major part of the circumnavigation this technique was applicable, as a significant decrease of the backscatter signal was observed at the top of the mixed layer. One roundtrip around the island took approximately 2hrs.

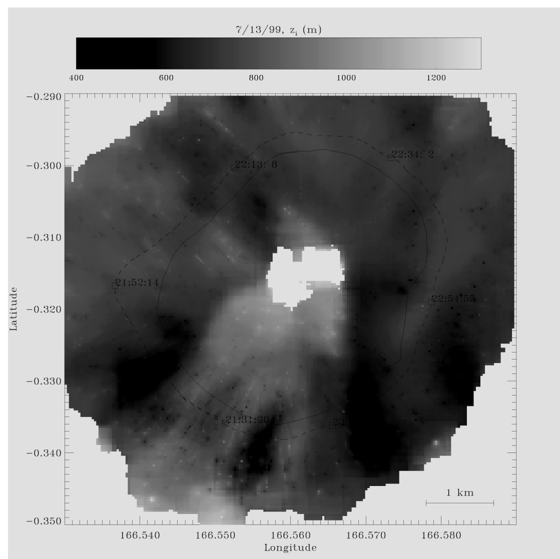

FIG. 3. Nauru's TIBL measured on 7/13/99 between 21:31UTC and 23:15UTC. The mean wind direction was northeast. Note that LT=UTC+11h so that we captured the morning evolution of the TIBL.

Fig.3 shows Nauru's TIBL in the morning local time on 07/14/1999. We found a complicated structure with a mixed layer top nearly a factor of two higher over the island than over the surrounding ocean. Note the wake effects along the TIBL which indicate regions with even a lower boundary layer height as the marine boundary layer.

In October of 1999, HRDL was used during the Cooperative Atmosphere/Surface Exchange Study (CASES-99) near Wichita, Kansas. The goal of CASES-99 was to investigate the stable nocturnal boundary layer (SBL) [5]. Turbulent mixing in the SBL is poorly understood. In constrast to the convective boundary layer (CBL) the spatial scales of velocity and thermal structures are much smaller, the boundary layer depth is much shallower, and turbulence tends to be intermittent. Because of HRDL's good range resolution and velocity accuracy it is ideally suited for SBL measurements.

During the month long deployment at the CASES-99 field site, HRDL documented the structure and evolution of internal gravity waves, shear instabilities, density currents, drainage flows and turbulence in the SBL. Fig. 3 shows a sample of one vertical-slice scan from a 20 min sequence recorded as a series of Kelvin-Helmholtz waves propagated over the field site.

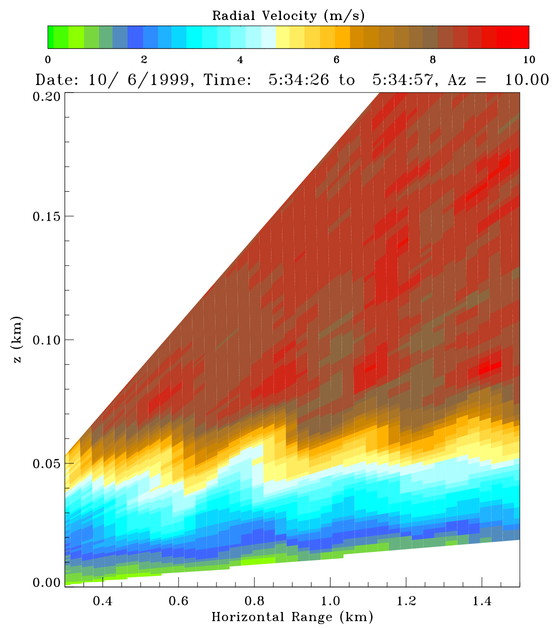

FIG. 4 Radial velocity field from a vertical-slice scan showing Kelvin-Helmholtz waves in the stable nocturnal boundary layer during CASES-99.

The image clearly shows over-turning wave-like structures. Spectral analysis of the entire sequence of scans reveal that these structures have a mean wavelength of 320m, a phase speed of 5.5ms and maximum amplitude centered at 55m AGL. This represents the first observation of a Kelvin-Helmholtz shear instability by a scanning Doppler lidar [6,7].

4. Summary

The performance of the NOAA/NCAR HRDL laser transmitter has been improved considerably permitting routine measurements on ground-based and shipborne platforms. The laser average power has been increased to 2W. A frequency stability of 0.2MHz rms can be maintained even in rough environment. These improvement will make airborne applications of HRDL possible which are already in development stage.

The high resolution of HRDL and its scanning capability allow important applications particularly in boundary layer research. For instance, we investigated the 3-d structure of the thermal internal boundary layer of an island site during the NAURU99 campaign. Further results of the CASES99 campaign highlighted the application of HRDL for the investigation of the stable boundary layer.

5. References

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